

Application of geoscience education for sustainable energy growth, development and training: A brief review

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Abstract

Geoscience education is not just about the present; It's about creating a sustainable future. The urgency to fully integrate renewable, sustainable and clean energy into our economic, environmental and social capabilities is paramount. The geoscience sector has taken a leading role in promoting the implementation of sustainable energy and its development. This paper, based on a desk study and literature review, attempts to address geoscientific principles of energy storage and distribution, energy efficient technologies and sustainable energy practices, implementation of energy policies to enforce sustainable energy practices, and real-world case studies of sustainable energy growth and development, challenges encountered and new trends in geoscientific commitment to sustainable energy. It particularly emphasizes the importance of geoscience education in addressing the complex energy challenges of the 21st century and highlights its practical application and role in shaping the future. It also highlights the potential of geosciences to create a sustainable future for future generations and inspires hope and inspiration for their role in our world.

Keywords: Geoscience education; Sustainable energy; Sustainability; Renewable energy

1. Introduction

As a discipline, geoscience is not just about studying planet Earth. It is about understanding how the Earth forms, what happened, how long it took to form, what elements were created during its formation and, most importantly, how the Earth changes over time. This long-term perspective is crucial for understanding and addressing sustainability issues. According to Wikipedia (2023), earth science education studies the Earth's physical features, processes, and systems and the natural and man-made events that shape it. Geoscience education is a multidisciplinary field encompassing various disciplines, including geology, geophysics, environmental sciences, oceanography, hydrological studies, sedimentology, and renewable energy studies. The United States Geological Survey website states that Earth science is about much more than just rocks and volcanoes; It also studies the natural resources we use and how water and ecosystems are connected. In addition, geosciences use tools and techniques from other scientific areas such as physics, chemistry, biology and mathematics.

The 2022 SEG webinar “The role of geosciences in the energy transition” establishes that geosciences are at the core of the energy transition. Oil and gas are formed in the Earth's geological formation, wind turbines are found, carbon dioxide is stored, and other essential minerals and energy sources are found (SEG Webinar, 2022). These factors illustrate the interconnectedness of geosciences with energy and its sustainability and show that geosciences host the most important natural resources from which energy is derived for industrial use and is sustainable for future growth.

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2. Background on the sustainable energy growth and development

Energy is sustainable when it meets the needs of the present without compromising the ability of future generations to meet their own needs, as the United Nations Brundtland Commission put it in its 1987 report “Our Common Future.” In their publication, the Routledge Tyler & Francis Group defines sustainable energy as any energy source that cannot be depleted and remains usable forever. Sustainable energy is intended to meet our energy needs without risking something going wrong or us running out of energy. Therefore, sustainable energy is urgently needed for our daily energy purposes.

Sustainable energy has minimal environmental and climate change impact, although costs are associated with creating and building sustainable energy opportunities. There are renewable energy sources such as wind, hydro, solar and geothermal energy that cause environmental damage but are more sustainable than fossil fuel sources (Zhang Wei *et al.*, 2021). Sustainable energy encompasses several dimensions of sustainability, such as environmental, economic and social dimensions (UNECE, 2020). The concept of sustainable energy has historically focused on emissions and energy security. Since 1990, the idea has expanded to include broader social and economic issues (Hammond & Jones, 2011). The current energy system contributes to many environmental problems, including climate change and air pollution resulting from burning fossil fuels in power plants and vehicles. Indoor air pollution is caused by cooking with polluting fuels such as wood, animal dung or kerosene. In 2019, 85% of global energy demand will be met by burning fossil fuels (UNECE, 2020).

Sustainably meeting existing and future energy needs is a critical challenge to the global goal of limiting climate change while maintaining economic growth and enabling an increase in living standards (Tester, 2012). Reliable and affordable energy, especially electricity, is critical for healthcare, education and economic development. Improving energy access in the least developed countries and cleaner energy is critical to achieving most of the United Nations' Sustainable Development Goals by 2030 (IE, 2021), covering topics from clean energy to climate action (Sarkodie, 2022). Sustainable Development Goal 7 calls for access for all to affordable, reliable, sustainable and modern energy, including universal access to electricity and clean cooking by 2030. Sustainable energy is the key to transitioning to a new energy model that can address three global challenges: environmental protection, energy security and socio-economic development (Repsol Global, 2024).

3. Importance of geoscience education in promoting sustainable energy growth, development and training

As previously mentioned, geoscience education studies the formation of the Earth, primarily involving rocks and fluids. This is an engineering understanding of the mechanisms of rocks and fluids in the subsurface and how their presence can be modelled, monitored and verified using geophysical, petrophysical and other techniques. This knowledge is applied to many low-carbon energy solutions, including sustainable mineral extraction, geothermal flow and underground storage. As a key player in promoting sustainable energy and development, geoscience education can be implemented through carbon capture and storage. This process captures excess carbon dioxide (CO₂) from the atmosphere, which causes global warming and traps the captured CO₂ in reservoir rocks or structural seals beneath the Earth's surface. In this way, geoscience helps curb the negative impacts of industrial use of fossil fuels while spreading the need for clean and sustainable energy.

Another aspect of geoscience education that promotes sustainable energy can be seen in natural gas. According to Rasoul Sorkhabi, (2022), natural gas is abundant and can be established as a source of electricity. For this reason, natural gas is often viewed as a bridge from today's fossil fuel-dominated civilization to a soon-to-be low-carbon world. He further states that natural gas emits 50% less CO₂ than coal and 25% crude oil. In summary, he predicts that geoscientists will soon be able to explore and discover natural gas deposits in sedimentary basins.

Furthermore, geoscientists assess the environmental impacts of energy production and consumption. This includes evaluating the effects of mining, drilling, and renewable energy installations on ecosystems and local communities (AGI, 2017). Geoscience education provides fundamental knowledge about Earth systems, including geology, hydrology, and atmospheric sciences. This understanding is essential for identifying and managing natural resources responsibly.

4. Geoscience education for sustainable energy sources

Renewable energy is energy obtained from natural resources replenished faster than used. Sunlight, wind, water, and geothermal energy are examples of such constantly renewed sources. Renewable energy production produces far lower

emissions than burning fossil fuels. Geoscientific principles are applied to renewable energy sources for their implementation, growth, sustainability, storage, and distribution for global economic use and future supply. Below are some insights into how geosciences achieve these goals.

4.1. Geothermal energy

Understanding geological features such as volcanic activity, hot springs and rock formations helps locate areas with high geothermal potential. Geologists study subsurface properties such as permeability and rocks' porosity to assess geothermal reservoirs' viability. Geological materials such as seismic survey maps and subsurface structures can identify potential geothermal sources. Geological processes such as heat and pressure convert organic material deposited in sedimentary basins over millions of years into coal, oil, and natural gas.

4.2. Wind energy

The 2017 Scottish Natural Heritage publication, *Siting and Designing Wind Farms* argues that landscape character is a critical feature for wind farm development regarding siting for wind and wind turbines. In addition, the siting of wind farms is related to the area's underlying geology, landform, soils, vegetation and land use settlement. Understanding a landscape's key features and characteristics is crucial to considering how new developments would affect it or how appropriate design might contribute to this. The strength and stability of the underlying rock formations are crucial factors for the foundation of wind turbines. Geoscientists evaluate potential geological hazards such as landslides or earthquakes before recommending a good location for wind turbines.

4.3. Hydropower

Building dams to harness water energy to provide electricity for economic use is critical to implementing clean energy and sustainability. The geological impacts of this invention could be recognized by analyzing rainfall patterns, river flows, and catchment areas when designing efficient hydropower projects. Geoscientists use GIS topography maps, among other things, to analyze river bodies, sediment transport, flow direction and intensity and estimate dam effects. Considering environmental impacts, they integrate geomorphology, river morphology, topography and geological formation to determine suitable locations for hydroelectric power plants.

4.4. Solar energy

The sun's energy in electromagnetic radiation interacts with the Earth's atmosphere, oceans and land masses. Geoscientists study the wavelength distribution of this radiation and how it affects the Earth's energy balance. Plate tectonics and solar resource distribution are other aspects of solar energy. Plate tectonics, the large-scale movement of the Earth's tectonic plates, has influenced the formation of continents and basins, thereby affecting the distribution of solar and wind resources around the globe. For example, areas near the equator tend to receive more direct sunlight due to the tilt of the Earth's axis (Liu *et al.*, 2017), giving residents of these areas more intense solar energy for their solar-powered machines. Climate change caused by greenhouse gas emissions impacts weather patterns and solar energy potential. Geoscientists are studying the relationship between climate and solar radiation to determine how future climate scenarios might affect the reliability of solar power generation (Li *et al.*, 2023).

5. Geoscience education for understanding energy storage and distribution

Geoscience education plays a role in developing expertise in energy storage and distribution systems, essential components of a sustainable and efficient energy infrastructure. This knowledge is critical as the world transitions to more renewable energy sources, often requiring innovative storage solutions due to their intermittent nature. Sustainable energy storage and distribution is about future use by generations, the uncertainty of availability at a given time, relieving the burden on power grids because of power overloads, etc. Energy supply from renewable sources such as wind or solar energy is subject to fluctuations and may not be able to meet current energy needs. Energy storage in the geological subsurface offers great potential capacity to bridge temporal gaps between solar or wind energy production periods and consumer demand. It can also help relieve pressure on power grids (Kabuth *et al.*, 2016). Therefore, energy storage is required to dampen these fluctuations and compensate for periods of low electricity production (Bauer *et al.*, 2017). Due to the intermittent nature of renewable electricity generation, storage is required at various time scales ranging from seconds to months and in storage sizes ranging from tens of kWh to tens of GWh. The geological subsurface can provide the large storage capacities required for long-term storage of large amounts of energy generated during extended periods of excess energy from wind or solar on a daily to seasonal scale (Bauer *et al.*, 2013). Geoscientists play a role in energy storage by identifying suitable geological formations for underground storage and optimizing materials for battery technologies. Suitable storage options for renewable energy include compressed air storage, natural gas, hydrogen gas produced by hydrolysis from electrical energy, or synthetic methane gas, which

in turn is produced from hydrogen (Bauer *et al.*, 2017). These gases can be stored in large quantities of hundreds of millions of m³ STP (LBEG, 2016), either in salt caverns or porous formations (Bauer *et al.*, 2017). Using geothermal energy methods, energy can be stored underground as heat (Kolditz *et al.*, 2013).

Gardiner, *et al.*, (2023) listed some options for geological underground energy storage at various scales in their 2023 publication entitled “Geosciences and the Energy Transition”. Geological hydrogen storage: Hydrogen gas is a “low carbon” energy source. Geological storage of hydrogen is expected to support a future hydrogen economy (Miocic *et al.*, 2022). Two main types of geological hydrogen storage are expected: salt caverns, where gas is injected into natural or man-made cavities in thick salt formations, and reservoir caprock systems (Gardiner, *et al.*, 2023). Salt caverns have been used to store hydrogen in the United States and the United Kingdom for decades (Zivar, *et al.*, 2021). However, they have limited capacity and geographical constraints on the availability of thick salt deposits (Gardiner *et al.*, 2023). For this reason, hydrogen storage in porous rocks is being investigated as a cost-effective solution. This involves injecting hydrogen into a porous and permeable reservoir formation, such as a saline aquifer or a depleted hydrocarbon field, with an impermeable seal (Gardiner *et al.*, 2023).

Natural gas storage: Natural gas production will decline significantly over 30 years. The IEA scenario “Net zero emissions by 2050” forecasts a 75% reduction from 2022 levels (IEA, 2022). There are two reasons for reducing natural gas consumption: first, natural gas combustion releases CO₂ and other compounds with global warming potential and negative environmental impacts, and second, increasing attention is being paid to the extent of diffuse emissions of methane, a powerful greenhouse gas associated with production, transportation and the storage of natural gas (Gardiner *et al.*, 2023). Therefore, there is an immediate need to implement technologies and practices to reduce fugitive emissions from current net gas supplies, including geological storage of natural gas (IEA, 2021). Natural gas is typically stored in man-made salt or rock caverns, depleted hydrocarbon reservoirs, abandoned mines, or saline aquifers, with depleted hydrocarbon fields typically providing the most significant storage capacity (Fang *et al.*, 2016). Geoscience courses provide students with the knowledge to understand and develop geological energy storage solutions, including:

5.1. Underground Pumped Hydro Storage (UPHS)

- Students learn about subsurface hydrogeology and rock mechanics to assess suitable sites for UPHS systems.
- Coursework covers fluid dynamics principles in porous media, critical for understanding water movement in these systems.

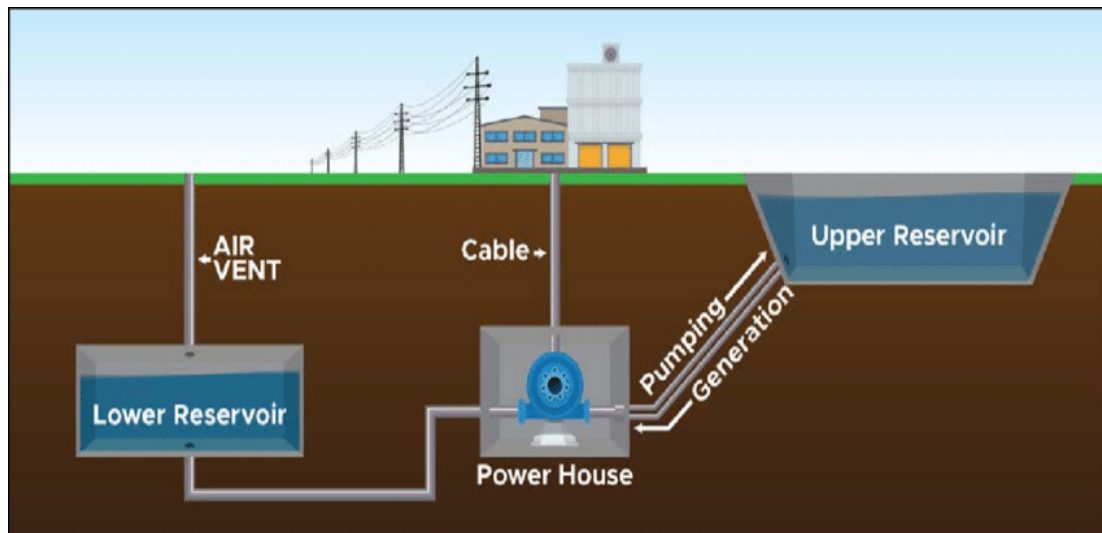


Figure 1 Conceptual diagram of an underground pumped storage hydropower project. (Source: Based on ESA 2019)

5.2. Compressed Air Energy Storage (CAES)

- Geoscience education provides insights into the characterization of suitable CAES geological formations (e.g., salt caverns, aquifers).
- Students study rock properties, structural geology, and geomechanics to evaluate the stability and capacity of potential storage sites (Brown *et al.*, 2021).

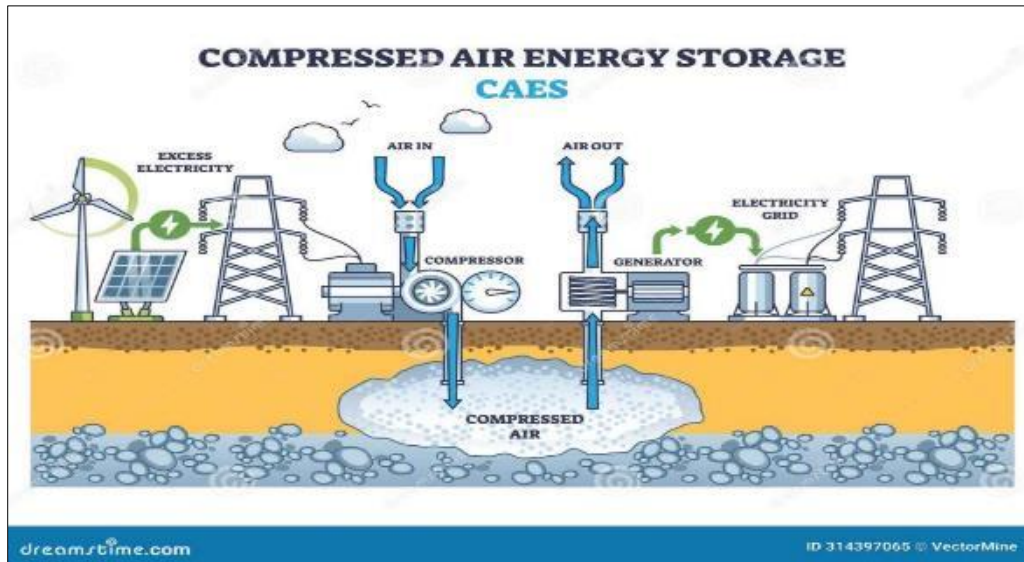


Figure 2 Compressed Air Energy Storage (Dreamtime.com)

5.3. Energy Distribution and Geoscience

Geoscience education also contributes to the understanding and optimization of energy distribution systems:

5.4. Pipeline Networks

- Students learn about geological hazards and how they can affect pipeline integrity, which is crucial for safe hydrocarbon transport.
- Courses in geomorphology and sedimentology help plan optimal pipeline routes and assess potential risks.

5.5. Electrical Grid Infrastructure

- Geoscience knowledge is applied to assess geologic risks to power transmission lines and substations.
- Students study natural hazards such as landslides, earthquakes, and soil liquefaction, which are critical considerations in infrastructure planning (Davis, 2021).



Figure 3 Electrical Grid Infrastructure (Google Photos)

5.6. Geoscience education for energy efficiency and conservation

Geoscience education addresses global energy challenges by providing students with the knowledge and skills necessary to develop and implement sustainable energy solutions. This section examines how geoscientists apply their

understanding of Earth systems to improve energy efficiency and conservation and how geoscience education prepares future professionals for this vital work.

6. Application of geoscience principles to energy-efficient technologies

Geoscientists apply their deep understanding of the Earth's subsurface, rock properties, and fluid dynamics to design and optimize technologies for energy storage, extraction, and utilization. This expertise is valuable in developing innovative energy solutions such as geothermal systems and carbon capture and storage (CCS) technologies.

6.1. Geothermal Energy Systems

Geothermal energy uses the earth's internal heat to generate electricity and for direct-use applications. Geoscientists play a critical role in identifying and characterizing suitable geothermal reservoirs by applying their knowledge of subsurface geology, heat flow, and fluid circulation (Johnson, 2019). For example, geoscientists in developing the Hellisheiði geothermal power plant in Iceland used advanced seismic imaging and geochemical analysis to map the underlying reservoir, optimize well placement, and ensure sustainable resource extraction.



Figure 4 Hellisheiði Geothermal Power Project, Hengill (Renewable Technology)

6.2. Carbon Capture and Storage (CCS)

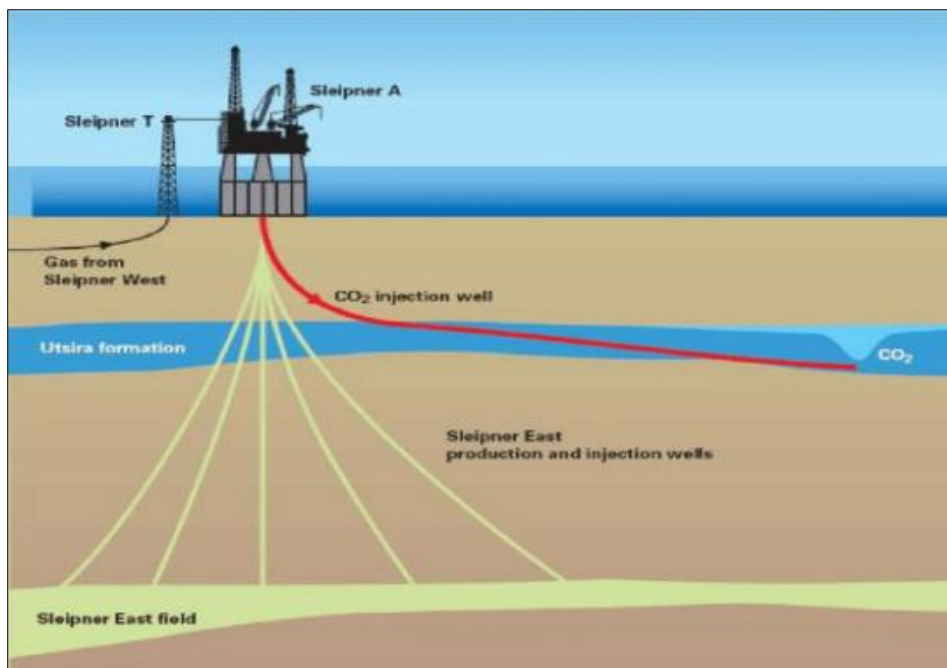


Figure 5 CO₂ storage project of Sleipner in Norway (Sengul, 2006)

The aim of CCS technology is to mitigate climate change by capturing CO₂ emissions from industrial sources and storing them in suitable geological formations. Geoscientists are critical in identifying and characterizing potential storage sites, assessing their capacity and integrity, and monitoring long-term storage performance (Brown *et al.*, 2018). The Sleipner CCS project in the North Sea demonstrates the successful application of geoscientific principles. A detailed understanding of the properties of the Utsira Sandstone Formation has enabled the safe storage of over 20 million tons of CO₂ since 1996.

7. Geoscience education for environmental impact assessment

Geoscience education enables students to assess the environmental impacts of energy production and consumption and develop sustainable energy solutions. This is achieved through specialist courses and various practical training courses.

7.1. Key Courses and Skills

- **Resource Evaluation:** Students learn energy potential assessment techniques, including seismic interpretation, well log analysis, and reservoir characterization.
- **Environmental Geology:** This course focuses on the interaction between human activities and geological processes, covering topics such as groundwater pollution, soil erosion, and natural hazards (Davis and Johnson, 2021).
- **Energy Systems Analysis:** Students gain an understanding of energy production and consumption, including life cycle assessment and techniques to optimize energy efficiency.

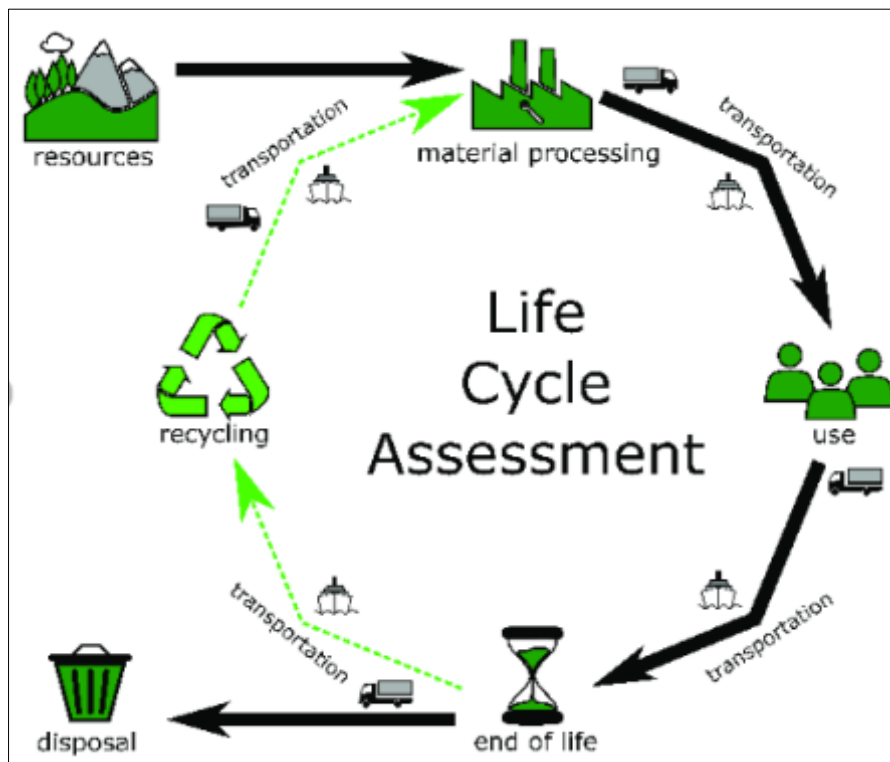


Figure 6 Simplified Life Cycle Assessment (Daniel Scharrer *et al.*, 2020)

7.2. Developing Sustainable Energy Solutions

- Through various related courses, students develop the ability to:
- Evaluate the environmental footprint of different energy sources
- Assess the potential impacts of energy projects on local ecosystems and communities
- Design mitigation strategies to minimize adverse environmental effects
- Optimize resource extraction and utilization to enhance sustainability

8. Geoscience education for energy policy and planning

8.1. Informing Energy Decision-Making

Geoscientists provide policymakers and planners with essential data and analysis on the availability, distribution and extraction of energy resources, informing decision-making on energy mix, infrastructure development and resource management. This information is crucial for developing a robust and sustainable energy policy.

8.2. Resource Assessment and Management

Geoscience education trains students in advanced techniques for resource assessment, including:

- Remote sensing and GIS for mapping energy resources
- Probabilistic resource estimation methods
- Basin modelling for hydrocarbon exploration
- Renewable resource potential evaluation (e.g., geothermal, solar, wind)

These skills enable geoscientists to provide accurate and comprehensive assessments of energy resources, informing policy decisions on resource allocation and management.

9. Geoscience education for workforce development and training

9.1. Technical Expertise for Energy Sector Careers

Geoscience programs provide students with the technical expertise necessary for careers in the energy sector, including roles in renewable energy, carbon capture and storage, and critical mineral extraction (Brown *et al.*, 2021).

9.2. Key Technical Skills

- Subsurface characterization and modeling
- Geophysical data acquisition and interpretation
- Reservoir engineering principles
- Geomechanics and rock physics

These skills are essential for various energy sector roles, such as:

- Geothermal resource specialist
- CCS site characterization geologist
- Energy resource analyst
- Environmental impact assessor

9.3. Fostering Interdisciplinary Collaboration

Geoscience education promotes interdisciplinary collaboration and enables graduates to work effectively in teams with engineers, policymakers, and other stakeholders to address complex energy challenges. Geoscience programs increasingly include:

- Team-based projects
- Industry partnerships and internships
- Cross-disciplinary courses with engineering and environmental science departments
- Communication and stakeholder engagement training

These experiences prepare geoscience graduates to:

- Translate technical information for non-specialist audiences
- Integrate diverse perspectives in problem-solving
- Navigate the regulatory and policy landscape of energy projects
- Contribute to multi-disciplinary teams in industry and government

10. Case studies and examples

Various sustainable energy initiatives worldwide have demonstrated the practical relevance of geoscience education. Case studies highlighting successful integration and outcomes have illustrated its application across various sectors. There are numerous examples showing how geoscience education has effectively promoted the adoption of sustainable energy practices, including:

10.1. The University of California, Berkeley: Community-Based Renewable Energy Project



Figure 7 Solar panels near the iconic Campanile on the UC Berkeley campus (credit: Kira Stall)



Figure 8 Olkaria Geothermal power project (credit: KenGen)

The University of California, Berkeley, has launched a program that combines geoscience education with hands-on projects to install renewable energy in surrounding communities. This program allows students to work closely with

community members to assess solar energy potential and create appropriate systems. As a result, the students developed greater energy awareness and the participating households achieved significant energy savings.

The ongoing Menengai Geothermal Project in Kenya is an additional illustration of how geoscience education has contributed to the development of sustainable energy.

10.2. The Energy and Resources Institute (TERI), India



Figure 9 Lake Turkana wind park (Twitter @KETRACO)



Figure 10 Noor Ouarzazate solar complex (Safaa Kasraoui)

In India, TERI has implemented several capacity building programs to improve geoscience education related to renewable energy. The focus of these projects is on educating residents about the use of solar and wind energy, incorporating geoscientific methods to assess site suitability and environmental impacts (Davis, 2021). By providing education and training on the use of renewable energy, TERI promotes sustainable development and autonomy in the energy sector

The Lake Turkana Wind Power Project in Kenya, the largest wind farm in Africa, is another notable example of geoscience studies used to assess wind patterns, ground stability and environmental impacts, enabling its construction (Lake Turkana Wind Power Project, 2023).

Geysers Geothermal Field in California is another project that relies heavily on geoscientific expertise for its operation and progress.



Figure 11 Power plant within the Geysers (Calpine)

These case studies illustrate the practical benefits of geoscience education and highlight its importance for sustainable energy development and community engagement. Geoscience education provides students with practical skills and theoretical understanding to address complex problems in managing energy resources and protecting the environment in their future careers.

11. Challenges and limitations

Despite its benefits, integrating geoscience education into sustainable energy training faces several challenges and barriers.

11.1. Limited resources

Many educational institutions lack funding for modern equipment, technology, and materials to teach advanced geoscience and sustainable energy concepts. This deficiency can hinder hands-on learning experiences critical to student engagement and understanding. Inadequate financial support can hinder the development of innovative curricula and limit access to modern equipment necessary for practical training. Technological advances offer promising opportunities to improve geoscience education but also present challenges in adapting curricula and training teachers. Integrating new technologies such as remote sensing and data analysis into educational programs requires continued professional development and investments in state-of-the-art laboratory facilities.

11.2. Outdated and rigid curriculum

Many academic institutions have not incorporated the latest developments in geosciences and renewable energy technology into their curricula. As a result, graduates may not have the skills and understanding required to meet the expectations of the modern world of work. Due to their frequent rigidity, the current curriculum makes it difficult to integrate new developments into sustainable energy trends and technologies. This inflexibility can lead to outdated curricula that fail to adequately train students for the needs of the modern workforce.

11.3. Interdisciplinary Collaboration

Geoscience teaching often occurs in isolation, limiting collaboration with other disciplines such as engineering, politics and social sciences. This lack of interdisciplinary interaction can prevent a holistic understanding of the complex challenges associated with sustainable energy. The gap between academia and the energy industry limits students' access to real-world applications and current practices in sustainable energy.

11.4. Limited Access to Resources

Access to educational resources such as research databases, modern laboratories, and field study opportunities is severely limited in many developing countries. This disparity may impact institutions' ability to provide comprehensive geoscience education with a focus on sustainable energy

12. Future direction and recommendation

12.1. Curriculum development

Curricula that meet industry needs should be integrated. Schools should regularly update their curricula to reflect current industry practices and technological breakthroughs to improve the relevance and effectiveness of geoscience education for sustainable energy. Academic researchers and industry specialists should work together to ensure that curricula meet industry needs and provide students with the practical skills they need to tackle real-world problems. Educational institutions should continue to update and expand their curricula to include new trends and technologies in sustainable energy.

12.2. Continuous development and training

The key to effective geoscience teaching lies in the professional development of educators. Sustainable energy and geoscience training programs and workshops can give educators the tools to explain challenging ideas. Ongoing training keeps educators abreast of new technological and pedagogy developments, ultimately benefiting students.

12.3. Fostering Interdisciplinary Collaboration

Geoscience education promotes interdisciplinary collaboration and enables graduates to work effectively in teams with engineers, policymakers, and other stakeholders to address complex energy challenges. Geoscience programs increasingly include:

- Team-based projects
- Industry partnerships and internships
- Cross-disciplinary courses with engineering and environmental science departments
- Communication and stakeholder engagement training

There should be collaboration between academia, industry and government agencies to strengthen and ensure that educational programs are aligned with industry needs and standards.

12.4. Investment in Resources

To modernize lab space and purchase state-of-the-art equipment such as GIS software and data analysis tools, schools may seek more funding. Access to cutting-edge materials can significantly improve experiential learning opportunities.

12.5. Public Outreach and Engagement:

There is an opportunity to increase public awareness and support for geoscience education by creating outreach initiatives that unite local communities to discuss sustainable energy. According to Wilson *et al.*, (2023), there is an opportunity to bridge the gap between education and community needs through citizen science initiatives, public lectures, and community workshops.

13. Conclusion

Growth, development and training in the field of sustainable energy are significantly supported by geoscience education. By incorporating topics related to sustainable energy into geoscience curricula, academic institutions are equipping their students to address global energy challenges. Numerous geoscience-driven sustainable energy initiatives and the

growth of a well-educated workforce are clear indicators of the impact of geoscience education on the energy sector. However, hurdles still need to be overcome, and ongoing work is needed to improve geoscience education and teaching for sustainable energy. The future of sustainable energy can be promoted through geoscience education through further study and multidisciplinary collaboration.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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